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PRODUCTION FACTORS FOR CORN IN THE NORTHWEST CORN BELT AREA

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PRODUCTION FACTORS FOR CORN IN THE NORTHWEST CORN BELT AREA [1]

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INTRODUCTION

A 38-million-acre area comprising western Minnesota, eastern North and South Dakota, and northwestern Iowa was designated as the research area for the North Central Soil and Water Conservation Field Station at Morris, Minn. Field plots described in this report were located in western Minnesota and eastern South Dakota. This area has many soil and climatic differences.

Several major soil associations in this area are the Barnes-Aastad-Flom, Kranzburg-Vienna-Moody, Clarion-Nicollet-Webster, Fargo, Bearden-Glyndon, and Poinsett-Sinai (1, 9).[6] Soil characteristics vary considerably because of differences in topography, climate, and parent material. The parent material of the Barnes-Aastad-Flom and the Clarion-Nicollet-Webster soil associations is glacial till. That of the Fargo and the Bearden-Glyndon soil associations is lacustrine material, that of the Kranzburg-Vienna-Moody is aeolian material, and that of the Poinsett-Sinai is probably alluvium.

Average annual precipitation in the area is 20 inches in the northern part and 27 inches in the southern part. Approximately 10 inches of precipitation are received during June, July, and August throughout the area. Individual locations may get slightly more or less than this amount. Temperature is characterized by wide variations in winter and summer. Average annual temperature ranges from 35°F. in the north to 45°F. in the south. The number of frost-free days ranges from 100 to 110 in the north and from 140 to 150 in the south.

Soil and crop management practice recommendations for this 20- to 27-inch rainfall area are highly dependent on the efficient use of stored soil moisture and natural rainfall. Because of year to year fluctuations in soil moisture, precipitation, and temperature, responses to management practices that involve fertilizer, corn population, and tillage are extremely variable. For example, in years of above normal rainfall, yield response to fertilizer may be significant and be most profitable at relatively high corn populations. In dry years, no response or even decreases in yields due to fertilizer may be obtained, and optimum corn stands may be relatively low. The interactions among the various management practices together with the moisture

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[6] Underlined numbers in parentheses refer to Literature Cited, page 38.

variable make quantitative evaluations and predictions of responses to practices extremely difficult.

The research technique described in this publication is designed to characterize soil management factors over an extensive area in which variations in climate exist.

RESPONSE SURFACE APPROACH

I. GENERAL

With the development of modern electronic computers, masses of data can be efficiently and rapidly analyzed. Associations between the many factors that influence yields can be calculated for characterizing the responses to them. These same factors can be put into a multiple regression equation for the purpose of predicting yields.

Several workers have used multiple regression analyses to estimate yields of corn for a number of controlled and uncontrolled variables. Englestad et al. (3) used multiple regressions in a study to determine the effect of surface soil thickness on corn yields. From a multiple regression containing 28 terms (certain first powers, second powers, and products of 10 measurements specified as variables) and using the ratio of "sums of squares for regression" to the total (yield) "sums of squares" as a criterion for the conformity of the regression model to the observations, they determined that this ratio was 54 and 85 percent for 1957 and 1958, respectively. The regression models were then recalculated using only those 5 terms out of 28 that provided the larger regression contributions. Parks and Knetsch (7) in Tennessee used a multiple regression model to describe the magnitude of corn yields in terms of N levels and drought intensity. The analyses of variance resulting from their regression model (which contained 4 terms) provided a ratio of regression sums of squares to yield sums of squares of 97 percent, using data observed over a 3-year period.

Pesek et al. (8) designed a series of studies for the purpose of representing the size of corn yields in terms of stand and N in a response surface model. The parameters estimated from the model were used in predicting the levels of the variables needed to provide an optimum in an economic sense. These scientists used a multiple regression model to represent production as a response surface and from this surface estimated the combination of input variables required for optimum production.

Crop production is a function of various factors, some of which may be controlled at different levels. In the equation $Y = F(X_1, X_2 \mid X_3, \ldots, X_g) + u$, (6) Y is yield per acre, X_1 and X_2 are nutrients applied per acre, X_3 through X_g are considered fixed in controlled quantities, and u represents uncontrolled variables. F is the response surface; knowledge concerning this function enables a researcher to summarize experimental results for the variables tested and to predict response for other values of these variables not actually tested but within the experimental limits (2).

Experimental designs and methods of analysis have been developed for fitting first- and second-degree polynomials to the response surface. In order to fit these second order polynomials to factorial designs, it is necessary to use factorial designs of 3^n or higher series. The disadvantages of fitting response surfaces to such designs relative to that of using designs specific for response surfaces include (a) difficulty in choosing only 3 levels of each factor in a 3^n factorial to adequately sample the response surface (6), (b) the coefficients B_{11} and B_{22} of the squared terms are estimated with relatively low precision in a 3^n factorial (2), and (c) the experiment becomes too large with more than 2 factors for the 4^n and 5^n series (6).

Composite designs were developed specifically for fitting second order response surfaces (2). These designs allow the fitting of a second order polynomial without having to include all levels of all factors in the design. For example, a 5^3 factorial requires 125 combinations, but by using

a central composite design the number of combinations is reduced to 20 to cover essentially the same ranges of the variables tested. Several limitations must be considered, however, when using central composite designs for field studies. The design was developed for industrial processes where variations are small and results are reproducible within very narrow limits. The center point level of each factor must be closely estimated so the model will fit the design. Also, since polynomials are usually not accurate when extrapolated, all predictions with either a factorial or composite design must be made within the range of values covered by the experiment (2).

Briefly, then, a response surface gives a complete summary of the results of an experiment and enables the researcher to predict responses for combinations of variables not actually tested in the experiment but lying within the ranges of those tested.

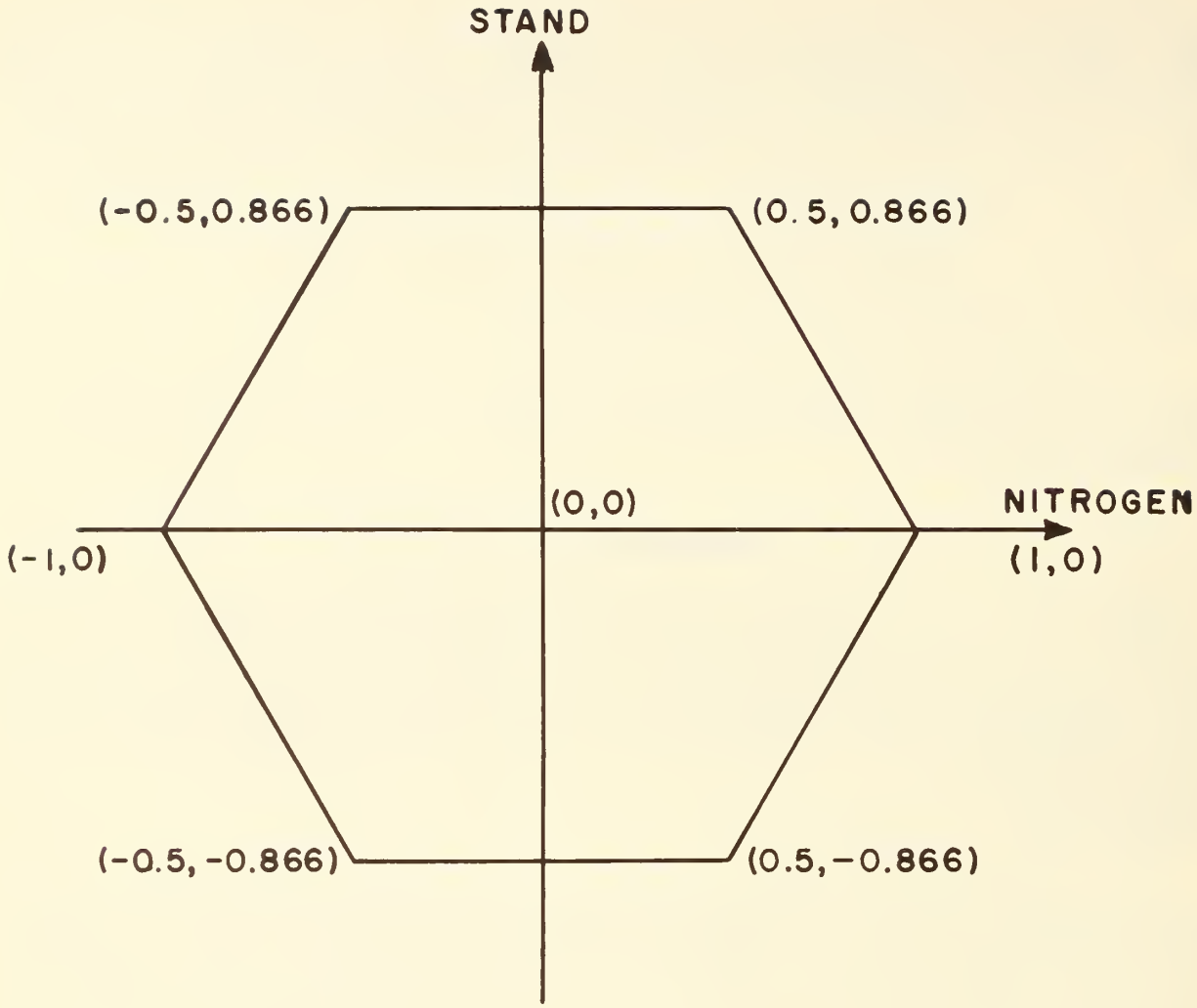
The objectives of this study were (a) to characterize the problem area for soil properties and crop environment in evaluating corn response to stand and fertility, and (b) to develop a yield prediction equation for estimating optimum combinations of stand and fertility for different levels of soil moisture.

II. EXPERIMENTAL DESIGN

Four major soils on which corn is extensively grown were selected for evaluating the production factors of corn. These were the Aastad, Barnes, Kranzburg, and Nicollet soils. Five experimental fields per soil were located in western Minnesota and eastern South Dakota for a 2-year period. The composite design used for 1960 was modified in 1961 because the 1960 results indicated changes that would improve the experiment. Both designs are presented in the following sections:

1960 Design

The 2-dimensional second order composite design had 5 levels of N and 3 levels of stand and was repeated at 2 P levels. The geometric representation of this design is shown in figure 1. The resultant design had 5 and 3 levels as measured in the horizontal and vertical directions, respectively. Nitrogen and stand were assigned to the horizontal and vertical dimensions, respectively, and were so selected that the center point (0,0) was estimated to give maximum yield. Table 1 gives the N and stand levels and their coded values for the 1960 design, and table 2 gives the experimental treatments. The analysis of variance is presented in table 3. One center point treatment was fertilized with K to determine response to this nutrient. Each field location had 2 replicates (20 treatments per replicate), and treatments were randomized within replicates. A sample field plot layout is shown in Appendix I (fig. 11). Single plots were 50 feet long and 13.3 feet wide (4 corn rows). The field plot layout at each Nicollet location was modified for a split plot application of P.



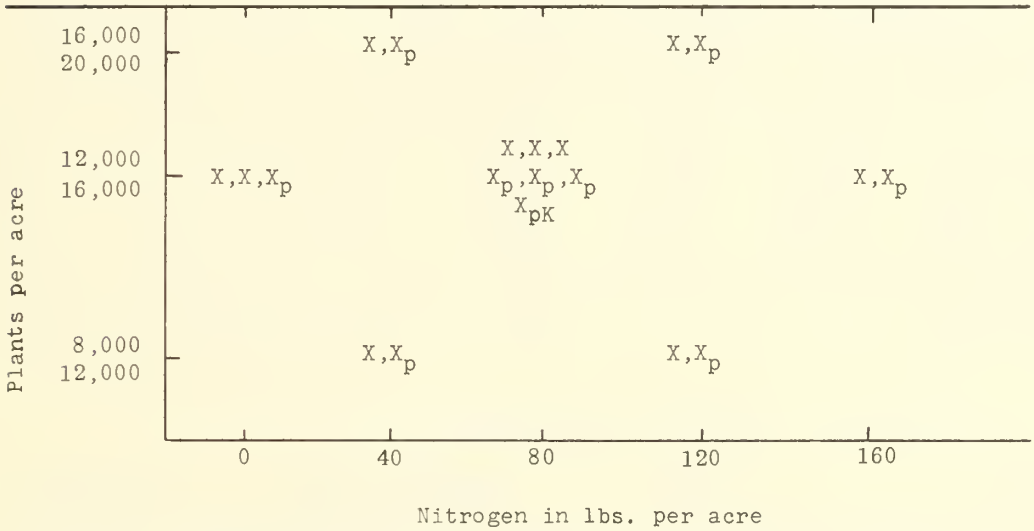
$$Y = b_0 + b_1 S + b_2 N + b_{11} S^2 + b_{22} N^2 + b_{12} NS$$

Figure 1.--Geometric representation of design used in 1960.

TABLE 1.--Levels of stand and nitrogen and their coded values for the 1960 composite design

N levels		Plants per acre				
Lb./acre	Coded value	Aastad	Barnes	Kranzburg	Nicollet	Coded value
0.....	-1.000	12,000	8,000	8,000	12,000	-0.866
40.....	-0.500	16,000	12,000	12,000	16,000	0
80.....	0	20,000	16,000	16,000	20,000	0.866
120.....	0.500					
160.....	1.000					

TABLE 2.--Experimental treatments for 1960[1] [2]



[1] X gives indicated treatment.
X_p gives indicated treatment + 17.5 lbs. of P per acre (40 lbs. P_2O_5).

X_{pK} gives indicated treatment + 17.5 lbs. of P + 50 lbs. of K per acre (60 lbs. K_2O).

[2] Stand levels for each soil are same as in table 1.

TABLE 3.--Analysis of variance for response surface design in randomized layout--1960

Location _____ Year _____ Trait _____

Source of variation	df	SS	MS	F
Total.....	36	S_1 = _____		
Mean.....	1	S_2 = _____		
Replications.....	1	S_3 =	_____	_____
Treatment.....	6	S_4 = _____	_____	_____
Linear.....	2	S_5 = _____	_____	_____
Quadratic.....	3	S_6 = _____	_____	_____
Lack of fit[1]	1	S_7 =	_____	_____
P.....	1	S_{10}=	_____	_____
P x Treatments.....	6	S_{11}= _____	_____	_____
P x Linear.....	2	S_{12}= _____	_____	_____
P x Quadratic.....	3	S_{13}= _____	_____	_____
P x Lack of fit.....	1	S_{14}=	_____	_____
Duplicate Plots.....	8	S_{17}= _____	_____	_____
Experimental Error.....	13	S_{18}= _____	_____	_____

Regression Coefficients

Variable	Symbol	Numerical value	Std. errors
Mean	b_0	_____	b_i _____
N	b_1	_____	b_{ii} _____
Stand	b_2	_____	b_{ij} _____
N^2	b_{11}	_____	
$Stand^2$	b_{22}	_____	
N x S	b_{12}	_____	

[1] Lack of fit is failure of the response surface to fit the data pooled over reps.

1961 Design

The design adapted was a 3-dimensional central composite second order design in incomplete blocks and had 20 treatment combinations for 3 factors at 5 levels each. The geometric representation is shown in figure 2 and consists of a cube plus an octahedron with vertices along the coordinate axes plus 6 points at the center. Treatment combinations are formed by a complete 2^3 factorial (8 corners of the cube), by an octahedron (6-star points outside the cube), and the center point of the configuration.

Levels of stand, N, and P and their coded values are given in table 4. Levels L2 and L4 for each variable are not in even increments since these would not fit the design. Sample calculations for determining these levels are given in Appendix II.

Treatment combinations and blocking arrangement in terms of coded values are given in table 5. This type of blocking aids in increasing precision yet permits a simple analysis since

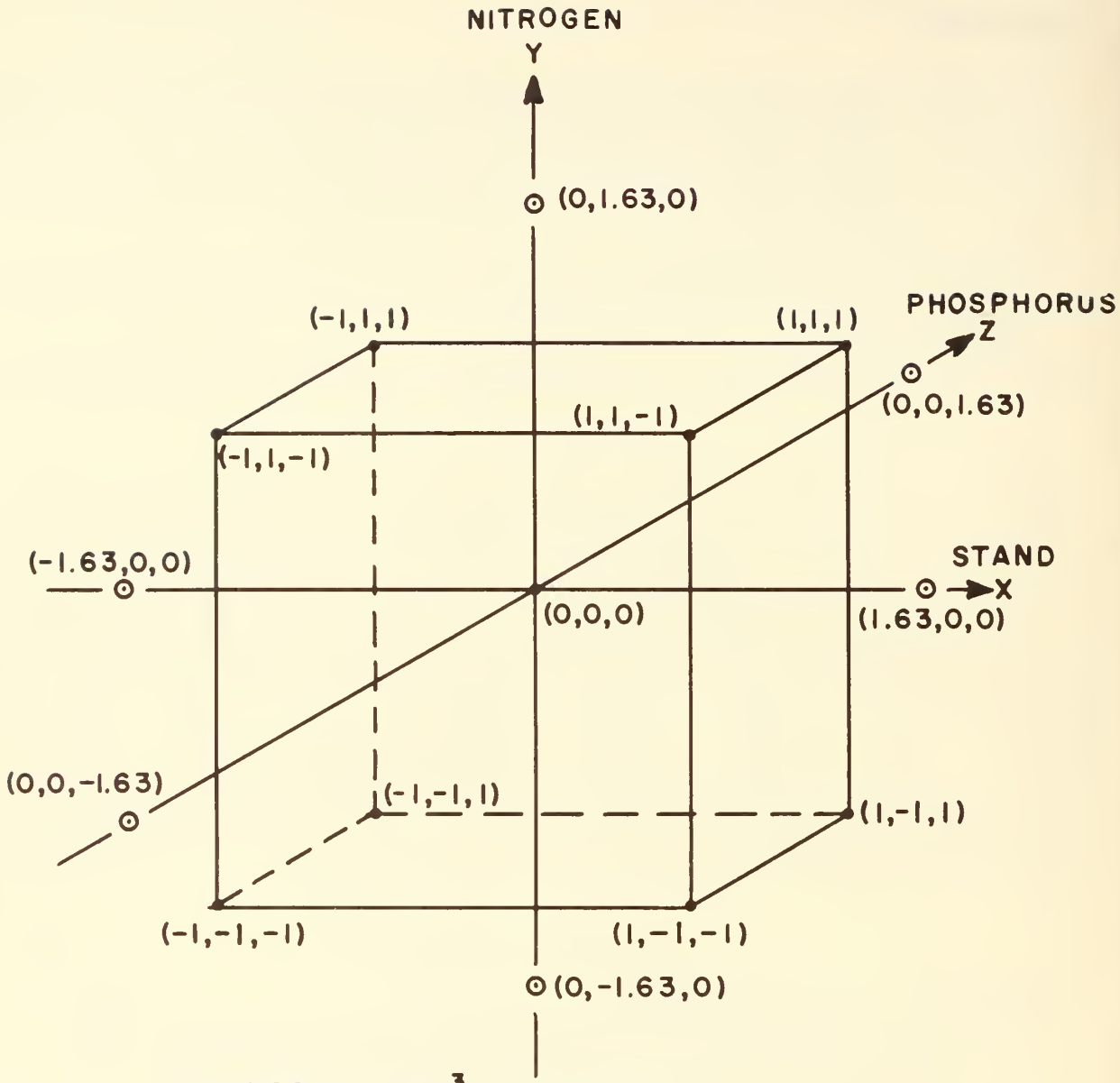
TABLE 4.--Levels of stand, nitrogen, and phosphorus and their coded values for the 1961 composite design

Level	Coded value	Number of plants per acre				N lb./ acre	P lb./acre[1]
		Aastad	Barnes	Kranzburg	Nicollet		
L1.....	-1.633	12,000	6,000	6,000	12,000	0	0
L2.....	-1.000	14,326	9,101	8,326	15,101	39	13.5
L3.....	0	18,000	14,000	12,000	20,000	100	35.0
L4.....	1.000	21,674	18,899	15,674	24,900	161	56.4
L5.....	1.633	24,000	22,000	18,000	28,000	200	70.0

[1] 13.5, 35, 56.4, and 70 lbs. P per acre are equivalent to 31, 80, 129, and 160 lbs. P_2O_5 per acre, respectively.

TABLE 5.--Treatment combinations and blocks for the central composite second order design with 3 X-variables and 20 treatment combinations

Block 1			Block II			Block III		
X_1 stand	X_2 N	X_3 P	X_1 stand	X_2 N	X_3 P	X_1 stand	X_2 N	X_3 P
-1.....	-1	1	-1	-1	-1	-1.633	0	0
1.....	-1	-1	1	-1	1	1.633	0	0
-1.....	1	-1	-1	1	1	0	-1.633	0
1.....	1	1	1	1	-1	0	1.633	0
0.....	0	0	0	0	0	0	0	-1.633
0..,..	0	0	0	0	0	0	0	1.633
						0	0	0
						0	0	0



$$Y = b_0 + b_1 S + b_2 N + b_3 P + b_{11} S^2 + b_{22} N^2 + b_{33} P^2 + b_{12} NS + b_{13} SP + b_{23} NP$$

Figure 2.--Geometric representation of composite design used in 1961.

the blocks are orthogonal to the coefficients in the fitted quadratic surface. Table 6 shows the analysis of variance for the 1961 design.

A sample field plot layout is given in Appendix I (Figure 12). Each location had 2 replicates (20 treatments per replicate), and treatments were randomized within blocks and blocks within each replicate. Plot size for each treatment was 50 feet long and 13.3 feet wide (4 corn rows).

TABLE 6.--Analysis of variance for response surface design in RB layout--1961

Location _____ Year _____ Trait _____

Source of variation	df	SS	MS	F
Total.....	40	S_1= _____		
Replications.....	1	S_2=	_____	
Blocks.....	2	S_3= _____	_____	
R x B.....	2	S_4= _____	_____	
Regression.....	10			
Mean.....	1	S_5= _____		
Linear.....	3	S_6= _____	_____	_____
Quadratic.....	6	S_7= _____	_____	_____
Lack of Fit[1]	19	S_8= _____	_____	_____
Within Blocks.....	6	S_9= _____	_____	

Regression Coefficients

Variable	Symbol	Numerical value	Std. errors
Mean	b_0	_____	b_i _____
Stand	b_1	_____	b_{ii} _____
N	b_2	_____	b_{ij} _____
P	b_3	_____	
Stand^2	b_{11}	_____	
N^2	b_{22}	_____	
P^2	b_{33}	_____	
S x N	b_{12}	_____	
S x P	b_{13}	_____	
N x P	b_{23}	_____	

[1] Lack of fit is failure of the response surface to fit the data pooled over reps plus the failure to have the same response surface at each rep.

III. EXPERIMENTAL PROCEDURE

All experimental areas were located on fields previously in corn or small grains for at least 3 years. The ammonium nitrate and superphosphate fertilizer for each treatment was thoroughly mixed with sand to a constant volume and broadcast by hand. This aided uniform spreading of the fertilizer over each plot. The fertilizer was then disked in before planting.

Corn was planted in 40-inch rows. Pioneer 377-A, a corn hybrid adapted to the problem area, was used at all locations. Atrazine 20 G (3 pounds active per acre in the row) and Aldrin (2 pounds active per acre in the row) were applied at planting time.[7] The plants were thinned to desired stands when they were about 3 inches tall. Each experimental area received one to three cultivations, depending on its weed problem. Thinning was rechecked after the last cultivation to insure correct stands.

Experimental sites on Nicollet soil were located and handled by personnel of the Minnesota Agricultural Experiment Station. South Dakota locations, selected by personnel at the South Dakota Agricultural Experiment Station and county agricultural extension agents, were handled by the experiment station. The remaining sites were the responsibility of ARS. They were located by ARS personnel and area soil scientists of the Soil Conservation Service on the farms of cooperators of Soil and Water Conservation Districts. Geographical locations of cooperators' farms for 1960 and 1961 are given in Appendix III.

Responsibility for field operations at each location was divided between research personnel and the farmer cooperator. Seedbed preparation was done by the farmer cooperator, planting by research personnel, and cultivation by either the cooperator or research personnel. (Nicollet sites were cultivated by the farmer-cooperators, and the remaining locations by research personnel.)

Since the experimental farms extended over a 400-mile route from Morris, it was necessary to transport all the equipment used for planting and cultivation (fig. 3). A tilt-top trailer was used, and it provided a convenient method for loading and unloading the planting and cultivating equipment. The mobile equipment setup was efficient to operate and easy to transport.

Figure 3.--Mobile equipment used for planting operations.

[7] Trade names are used in this publication solely to provide specific information. Mention of a trade name does not constitute a guarantee or warranty and does not signify that the product is approved to the exclusion of other comparable products.

EXPERIMENTAL RESULTS AND DISCUSSION

I. GENERAL

This study had two objectives: (a) to characterize the problem area for soil properties and crop environment, and (b) to develop a yield prediction equation for determining management levels based on the soil properties and environment. This response surface approach has adequately accomplished the first objective, but additional studies are necessary to obtain complete accomplishment of the second objective. Multiple regressions to date, using the ratio of regression sums of squares to total (yield) sums of squares as a criterion for the conformity of the regression model to the observations, have shown this ratio to be 75 percent. Further refinement of the prediction equation is desirable.

II. CHARACTERIZATION OF THE PROBLEM AREA

Soil Moisture

Previous work (5) in western Minnesota showed that from the time corn is 1 foot tall until kernels are formed, evapotranspiration is more than the average rainfall received during that period, and that corn extracts soil water to a depth of at least 5 feet. Therefore, depending on the amount and distribution of rainfall during the growing season, corn yields can be greatly influenced by the stored soil moisture at planting time.

Average maximum available soil moisture (as measured by the 1/3- and 15-atmosphere values) for 1960 locations is given in table 7. The soils shown all have adequate water storage

TABLE 7.--Average inches of maximum available soil moisture for 1960 locations.[1]

Depth in inches	Avg. avail. inches H_2O per depth	Range of avail. inches H_2O per depth	Depth in inches	Avg. avail. inches H_2O per depth	Range of avail. inches H_2O per depth
	Aastad Soil			Barnes Soil	
0 - 6....	1.28	0.89 - 1.74	0 - 6....	1.04	0.90 - 1.20
6 - 12...	1.26	1.10 - 1.32	6 - 12...	1.12	0.98 - 1.31
12 - 18...	1.30	1.03 - 1.52	12 - 18...	1.17	0.99 - 1.38
18 - 24...	1.39	1.24 - 1.58	18 - 24...	1.18	0.82 - 1.46
24 - 36...	3.03	2.76 - 3.90	24 - 36...	2.62	2.05 - 3.34
36 - 48...	2.67	1.98 - 3.15	36 - 48...	2.85	2.47 - 3.18
48 - 60...	2.87	2.73 - 3.02	48 - 60...	2.86	2.63 - 3.18
Total...	13.80	12.76 - 15.63		12.84	11.29 - 14.29
	Kranzburg Soil			Nicollet Soil[2]	
0 - 6....	1.26	0.87 - 1.52	0 - 6....	1.21	0.96 - 1.40
6 - 12...	1.30	0.96 - 1.65	6 - 12...	1.16	0.98 - 1.39
12 - 18...	1.34	1.10 - 1.54	12 - 18...	1.16	0.96 - 1.39
18 - 24...	1.43	1.09 - 1.56	18 - 24...	1.34	1.01 - 1.71
24 - 36...	2.39	1.90 - 2.98	24 - 36...	3.11	2.67 - 3.38
36 - 48...	2.67	2.28 - 2.98	36 - 48...	3.39	2.72 - 4.02
48 - 60...	2.76	2.44 - 3.04	48 - 60...	3.37	3.14 - 3.68
Total...	13.15	10.88 - 14.95		14.74	12.44 - 16.97

[1] Measured by 1/3- and 15-atmosphere tensions.
[2] Values are for 1961 locations.

capacity to the 5-foot depth, but did not attain 100 percent recharge during the 2 years studied. The stored soil water that is available, therefore, must be utilized efficiently to obtain maximum yields.

Available soil moisture at planting time in 1960 and 1961 are presented in tables 8 and 9, respectively. A range of 3.18 to 10.47 inches was measured for the 2 years studied; consequently, a wide variation of soil water existed at planting time. Most of the experimental locations had 6 to 8 inches of stored soil moisture at planting time (fig. 4). Multiple regression results indicate that 6 inches of available soil water at planting time is the minimum moisture reserve necessary to produce about 70 bushels of corn per acre with normal precipitation for center point stands. Results of soil moisture determinations for a 6-year period (4) showed that one-third of the locations had less than 6 inches of stored soil moisture at planting time.

TABLE 8.--Inches of available soil moisture at planting time--1960

Location (farm)[1]	Soil depth in inches							
	0-6	6-12	12-18	18-24	24-36	36-48	48-60	Total
				Aastad Soil				
Hubbard.....	0.82	0.94	0.59	0.58	1.66	1.60	1.30	7.49
Johnson.....	0.69	0.81	0.76	0.63	1.75	1.96	1.91	8.51
Krueger.....	1.18	0.91	1.02	0.88	2.08	2.42	1.98	10.47
Rieppel.....	0.98	0.88	0.72	0.48	1.36	1.29	1.62	7.33
W. C. Exp. Sta.	1.14	1.02	0.95	0.74	0.74	0.68	0.77	6.04
				Barnes Soil				
Cook.....	0.72	0.98	0.92	0.64	0.95	1.00	1.05	6.26
Frensko.....	0.80	0.89	0.82	0.81	1.73	1.31	0.87	7.23
Grothe.....	1.06	1.26	1.24	1.12	1.94	0.94	0.96	8.52
Pufahl.....	1.20	0.92	0.66	0.25	0.07	0.08	0.08	3.26
Siira.....	0.60	0.78	0.70	0.74	1.34	1.22	1.08	6.46
				Kranzburg Soil				
Berger.....	1.24	1.22	1.00	1.00	1.54	0.58	0.56	7.14
Puhr.....	1.10	0.86	1.08	0.91	0.36	0.12	0.18	4.61
Heikes.....	0.99	1.06	1.14	1.08	2.10	1.68	0.96	9.01
Nelson.....	0.68	0.61	0.58	0.44	0.32	0.16	0.39	3.18
Wilson.....	1.16	1.13	1.12	1.01	1.74	0.52	0.52	7.22
				Nicollet Soil[2]				
SW. Exp. Sta...	1.76		1.42		1.54	1.32	1.32	7.36
Hansen.....	2.05		1.30		1.21	1.13	1.13	6.82
Bushard.....	1.99		1.52		1.79	1.23	1.23	7.76
Engstrom.....	2.03		1.81		2.15	2.23	2.23	10.45
S. Exp. Sta....	1.86		1.54		1.82	1.67	1.68	8.57

[1] Locations of cooperators' farms are given in Appendix III.
[2] Sampling depths were 0-12 and 12-24 inches in the upper 2 feet.

TABLE 9.--Inches of available soil moisture at planting time--1961[1]

Location (farm)	Soil depth in inches							
	0-6	6-12	12-18	18-24	24-36	36-48	48-60	Total
				Aastad Soil				
Hubbard.....	0.79	0.73	0.54	0.48	0.99	1.78	1.50	6.81
Johnson.....	0.94	0.76	0.62	0.57	1.53	1.42	1.41	7.25
Krueger.....	0.76	0.69	0.70	0.58	1.63	1.54	1.47	7.37
Rieppel.....	0.72	0.78	1.25	0.74	1.58	1.12	1.23	7.42
W. C. Exp. Sta.	1.06	1.27	0.82	0.77	1.40	2.02	1.26	8.60
				Barnes Soil				
Cook.....	1.02	0.79	0.78	0.56	1.46	1.78	2.12	8.51
Frederick.....	0.80	0.66	0.61	0.48	1.18	1.41	1.39	6.53
Frensko.....	0.78	0.74	0.68	0.74	1.56	1.30	0.82	6.62
Grothe.....	0.91	0.89	0.78	0.86	1.64	1.70	1.58	8.36
Pufahl.....	0.74	0.74	0.60	0.62	1.38	1.52	1.68	7.28
				Kranzburg Soil				
Berger.....	1.18	0.96	0.88	0.98	1.64	0.91	0.87	7.42
Foster.....	0.67	0.52	0.77	0.68	0.85	0.39	0.44	4.32
Heikes.....	0.74	0.78	0.80	0.86	1.77	0.99	1.06	7.00
Nelson.....	1.00	0.74	0.83	0.58	0.87	0.67	0.43	5.12
Wilson.....	1.00	0.96	0.84	0.80	1.37	1.40	1.39	7.76
				Waubay-like Soil				
Juel.....	1.14	1.00	0.79	0.64	1.24	0.77	1.16	6.74

[1] Soil moisture not measured at planting time on Nicollet sites.

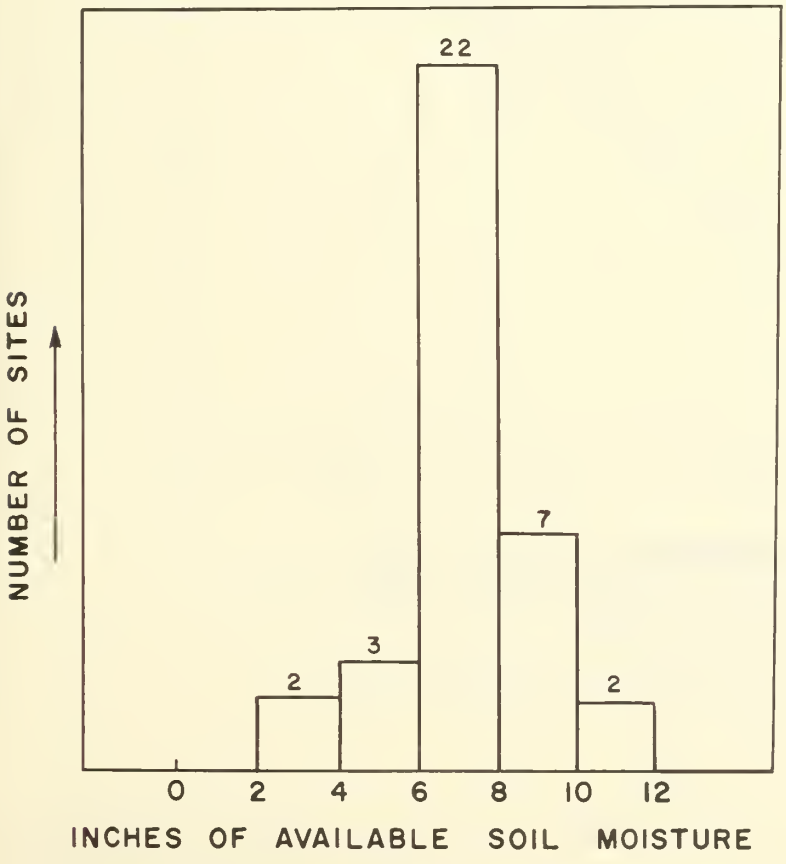


Figure 4.--Frequency diagram of available soil moisture to 5 feet at planting time for 1960 and 1961. (Does not include 1961 Nicollet locations because available soil moisture at planting time was not determined.)

Precipitation

Rainfall measured during the growing season varied from 5.58 to 20.78 inches during the 2 years studied (tables 10 and 11). The effect of precipitation on corn growth depends on the amount and distribution during the growing season. Since corn uses most of its required water from 1-foot plant height to kernel formation (July 1-August 15), the rainfall it gets during this period is highly beneficial to corn growth. Figure 5 shows the effect of July rainfall on yield increase per 1000 plants using 1960 and 1961 results for Aastad, Barnes, and Kranzburg locations.[8] Yield increase per 1000 plants was calculated from the response surfaces by dividing the greatest yield difference by the number of plants (in 1000's) to produce this yield change. Only locations having a positive response to stand were used. As a practical application, yield increase per 1000 plants at each location could be calculated by substituting average July rainfall into the regression equation. Although this relationship does indicate the effect of rainfall during the critical growth period, additional data are needed for refinement.

[8] Complete data for Nicollet sites were not available when this correlation was calculated.

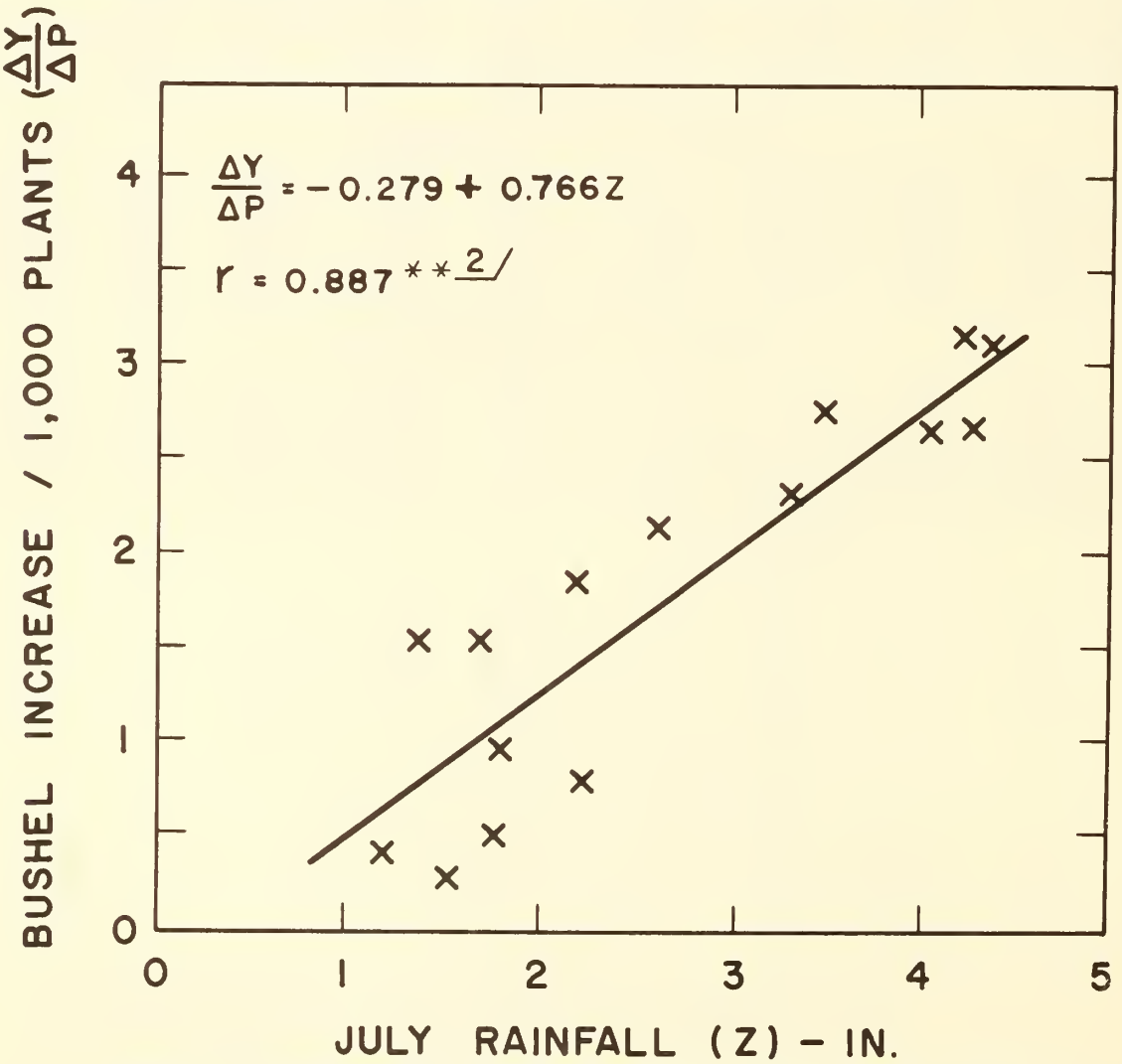


Figure 5.--Corn yield increase per 1000 plants vs. July rainfall in western Minnesota and eastern South Dakota.[1]

[1] Yields used for this regression were for the 100 N and 35 P fertility level only.
[2] **shows statistical significance at the 1 percent level.

TABLE 10.--Inches of rainfall from planting time to September 15, 1960

Location (farm)	May	June	July	August	September	Total
			Aastad Soil			
Hubbard.....	0.66	3.98	1.20	5.96	0.70	12.50
Johnson.....	0	4.63	1.36	4.73	1.45	12.17
Krueger.....	0	3.01	1.98	4.20	1.13	10.32
Rieppel.....	0.54	3.62	1.33	7.82	0.50	13.81
W. C. Exp. Sta...	0.84	6.08	1.74	5.89	0.61	15.16
			Barnes Soil			
Cook.....	0.47	7.20	1.16	6.86	0.80	16.49
Frensko.....	0	3.63	1.17	5.50	1.20	11.50
Grothe.....	0.66	3.05	2.55	6.00	0.90	13.16
Pufahl.....	0.52	3.71	1.55	3.25	1.03	10.06
Siira.....	1.07	5.02	2.18	6.73	0.70	15.70
			Kranzburg Soil			
Berger.....	0	3.99	0.55	6.00	1.60	12.12
Puhr.....	0	4.27	0.39	4.20	2.44	11.30
Heikes.....	0	2.16	0.49	5.73	1.85	10.23
Nelson.....	0.46	3.69	1.39	4.40	1.59	11.53
Wilson.....	0.12	2.98	1.75	6.67	2.65	14.17
			Nicollet Soil			
Bushard.....	3.19	2.32	1.50	5.77	1.30	14.08
Engstrom.....	7.35	1.25	0	1.50	0.60	10.70
Hansen.....	5.24	2.21	4.31	5.30	3.25	20.31
SW. Exp. Sta.....	-	2.78	3.95	4.31	0.92	11.96
S. Exp. Sta.....	6.64	5.09	2.26	2.59	0.84	17.42

TABLE 11.--Inches of rainfall from planting time to September 15, 1961

Location (farm)	May	June	July	August	September	Total
			Aastad Soil			
Hubbard.....	0	3.22	3.65	4.17	2.90	13.94
Johnson.....	0	2.64	3.41	0.85	2.00	8.90
Krueger.....	0	2.65	7.09	1.50	1.49	12.73
Rieppel.....	0	1.90	1.12	1.17	2.76	6.95
W. C. Exp. Sta. ..	0	1.14	1.79	2.99	2.42	8.34
			Barnes Soil			
Cook.....	0.65	1.75	2.66	3.34	2.31	10.71
Frederick.....	0	2.34	3.30	3.00	2.69	11.33
Frensko.....	0	4.70	4.25	3.15	1.15	13.25
Grothe.....	0.35	1.26	2.17	3.55	3.80	11.13
Pufahl.....	0.75	0.80	0.87	1.91	2.88	7.21
			Kranzburg Soil			
Berger.....	0.32	3.06	4.21	0	0.70	8.29
Foster.....	0	5.14	2.09	3.20	0.82	11.25
Heikes.....	0.33	3.71	3.48	3.69	0.60	11.81
Nelson.....	0	2.10	0.40	2.40	1.32	6.22
Wilson.....	0.08	1.78	3.99	2.40	0.69	8.94
			Nicollet Soil			
Grewe.....	1.00	2.39	6.47	2.10	2.33	14.29
Hansen.....	2.95	2.61	4.05	2.30	2.20	14.11
SW. Exp. Sta.	2.55	2.31	5.47	1.72	1.40	13.45
S. Exp. Sta.	5.10	0.98	6.73	5.65	2.32	20.78
			Waubay-like Soil			
Juel.....	0	1.50	1.00	2.88	0.20	5.58

Relationship among Rainfall, Stored Soil Moisture, and Corn Yields

Simple relationships[9] determined for available soil moisture to a depth of 5 feet at planting time versus corn yields gave r^2 values of 0.50 and 0.09, respectively, for 1960 and 1961 (4).[10] A highly significant soil moisture-corn yield relationship occurred in 1960. All locations received below average July rainfall, so the corn relied more on stored soil water during the critical growth period. In 1961, however, above average July rainfall at most locations minimized the effect of stored soil moisture on corn yields ($r^2 = 0.09$) and resulted in a highly significant July precipitation-corn yield relationship. When only those locations with below average July rainfall were used, the soil moisture-corn yield relationship in 1961 was significant ($r^2 = 0.69$). The importance of stored soil moisture at planting time on subsequent corn yields will be influenced by precipitation during the growing season, particularly rainfall received during the critical growth period.

Response to Input Variables

Yield responses to stand, N, and P are discussed in the following paragraphs. Average corn yields for treatments at each location are presented in tables 12 and 13.

Stand--During the 2 years studied, 13 of 40 locations showed positive response to stand--3 locations in 1960 and 10 in 1961 (tables 14 and 15). On Aastad sites, no stand response was obtained for either year studied, whereas this response occurred on the other soils for 1 or both years. No definite reason is known for this lack of response on Aastad soils because available soil moisture reserves were adequate, and N, P, and K fertility (on highly fertilized plots) was not limiting. Apparently, other factors not measured caused the lack of stand response.

In 1960, 3 locations (Pufahl, Nelson, and Puhr) showed negative response to stand. This was probably caused by low soil moisture reserves at planting and below average rainfall during the critical growth period so the higher stands ran out of water, thus, resulting in decreased yields. The 1961 locations showing response to stand were generally associated with above average precipitation during the critical growth period. Apparently, no other factor was seriously limiting so with more favorable moisture conditions yields increased with higher stands.

Nitrogen--Of the 40 locations studied during the 2 years, 13 showed response to N--4 in 1960 and 9 in 1961 (tables 14 and 15). No definite relationship between N response and available soil moisture at planting time was observed during the 2 years. Engstrom (1960) had 10.45 inches of stored soil water and Foster (1961) had 4.32 inches. The remaining locations showing response to N had 6 to 8 inches of stored moisture at planting time. The poor overall N response occurring in 1960 appeared to be related to below average rainfall during the critical growth period. In 1961, however, the more favorable moisture conditions during this period were probably the main reason for the increased response at most locations.

In 1961, 11 locations were situated adjacent to the 1960 experimental areas. Of these 11 locations, 5 showed response to N, but only 2 (Grothe and the Southwest Experiment Station) gave response in 1960 also. Frensko, Heikes, and the Southern Experiment Station showed N response only in 1961, and this appeared related to above average July rainfall (4.25, 3.48, and 6.73 inches, respectively). Grothe received below average July rainfall for both years so the response did not appear related to precipitation during the critical growth period. The Southwest Experiment Station, however, received above average July rainfall for both years.

Response to N, therefore, appeared more related to rainfall during the critical growth period than to any other factor. In 1960, NO_3--N (initial + 2 week incubation) measured on the 0- to 6-inch depth showed no consistent relation to N response. Also no definite relationship

[9] Simple relationships for 1960 included all Aastad, Barnes, Kranzburg, and Nicollet sites, whereas for 1961 the Nicollet sites were not included since soil moisture at planting time was not determined.

[10] The r^2 value of 0.55 for 1960 given in reference (4) does not include Nicollet locations.

TABLE 12.--Average corn yield in bushels per acre for treatments at each experimental location--1960

Treatment			Locations (farms) on Barnes soil					Locations (farms) on Kranzburg soil				
Stand 1000's	N lb./acre	P lb./acre[1]	Cook	Frensko	Grothe	Pufahl	Siira	Berger	Heikes	Nelson	Puhr	Wilson
8	40	0	84	78	56	44	52	42	48	40	50	56
8	40	17.5	72	74	63	38	60	40	59	46	48	56
8	120	0	79	74	67	41	54	40	56	32	48	53
8	120	17.5	83	74	74	32	57	38	48	34	47	62
12	0	0	96	84	38	29	67	38	59	39	50	60
12	0	17.5	108	86	44	14	55	38	60	24	46	62
12	80	0	97	88	74	26	62	32	66	28	45	64
12	80	17.5	96	83	80	17	72	28	73	26	45	62
12[2]	80	17.5	100	86	78	22	64	23	66	20	38	63
12	160	0	92	88	88	30	60	28	66	32	40	68
12	160	17.5	92	84	78	19	74	25	72	28	44	59
16	40	0	106	94	78	22	60	36	58	19	27	56
16	40	17.5	109	98	71	20	76	19	62	13	30	66
16	120	0	102	86	92	12	58	26	64	28	34	52
16	120	17.5	103	82	86	10	81	36	68	11	24	54

continued

See footnotes on following page.

TABLE 12.--Continued

Treatment			Locations (farms) on Aastad soil					Locations (farms) on Nicollet soil				
Stand 1000's	N lb./acre[1]	P lb./acre	Hubbard	Johnson	Krueger	Rieppel	W.C. Sta.	Bushard	Engstrom	Hansen	S. Sta.	SW. Sta.
12	40	0	42	63	88	72	70	91	70	106	72	81
12	40	17.5	73	63	99	70	76	96	74	91	77	82
12	120	0	68	86	92	72	72	92	90	96	66	87
12	120	17.5	58	82	110	104	80	95	93	98	90	106
16	0	0	76	64	106	50	64	78	62	102	71	66
16	0	17.5	76	60	120	46	55	78	66	108	78	70
16	80	0	54	75	100	79	69	90	84	108	82	83
16	80	17.5	61	85	110	93	74	84	89	101	88	96
16[2]	80	17.5	50	76	112	85	75	--	--	--	--	--
16	160	0	60	74	93	100	70	86	88	104	80	95
16	160	17.5	59	72	114	98	76	76	93	106	87	106
20	40	0	56	68	130	69	78	100	75	123	82	85
20	40	17.5	62	78	117	66	74	87	70	116	91	102
20	120	0	64	76	120	95	78	99	104	101	82	92
20	120	17.5	62	88	104	94	66	84	97	121	88	102

[1] 17.5 lb. per acre P is equal to 40 lb. per acre P_2O_5.
[2] 50 lb. per acre K broadcast on this plot (60 lbs. K_2O).

TABLE 13.--Average corn yields in bushels per acre for treatments at each experimental location--1961

Treatment			Locations (farms) on Aastad soil				
Stand	N lb./acre	P lb./acre	Hubbard	Johnson	Krueger	Rieppel	W. C. Exp. Sta.
12,000....	100	35	94	69	72	32	74
14,326....	38	13.5	99	79	56	40	86
14,326....	38	56.4	106	72	63	24	80
14,326....	161	13.5	108	73	78	28	74
14,326....	161	56.4	98	74	84	58	78
18,000....	0	35	90	67	53	38	84
18,000....	100	0	102	78	61	32	84
18,000....	100	35	105	80	80	41	79
18,000....	100	70	94	82	88	4	84
18,000....	200	35	98	81	84	24	88
21,674....	38	13.5	100	63	60	20	82
21,674....	38	56.4	104	82	57	42	71
21,674....	161	13.5	110	71	61	26	77
21,674....	161	56.4	101	74	86	20	60
24,000....	100	35	100	73	72	36	82
Additional treatments							
18,000....	0	0	96	74	44	30	48
18,000[2] ..	100	35	103	82	74	46	72

Treatment			Locations (farms) on Barnes soil					Waubay-like soil
Stand	N lb./acre	P lb./acre	Cook	Frederick	Frensko	Grothe	Pufahl	Juel
6,000....	100	35	65	64	50	50	27	42
9,101....	38	13.5	86	82	62	51	29	42
9,101....	38	56.4	80	70	68	48	34	60
9,101....	161	13.5	74	74	72	60	45	58
9,101....	161	56.4	88	80	70	60	36	54
14,000....	0	35	96	81	72	31	33	36
14,000....	100	0	84	76	72	54	32	28
14,000....	100	35	89	91	86	63	30	46
14,000....	100	70	93	94	88	63	36	36
14,000....	200	35	86	92	87	52	33	40
18,900....	38	13.5	89	80	82	44	32	50
18,900....	38	56.4	102	98	76	51	34	42
18,900....	161	13.5	94	96	78	63	30	45
18,900....	161	56.4	91	100	89	62	32	50
22,000....	100	35	98	95	85	66	28	24
Additional Treatments								
14,000....	0	0	74	66	61	48	24	32
14,000[2] ..	100	35	87	88	80	63	24	36

TABLE 13.--Continued

Treatment			Locations (farms) on Kranzburg soil				
Stand	N lb./acre	P lb./acre[1]	Berger	Foster	Heikes	Nelson	Wilson
6,000....	100	35	56	49	62	22	50
8,326....	38	13.5	57	46	58	24	71
8,326....	38	56.4	65	44	64	26	56
8,326....	161	13.5	61	50	76	28	65
8,326....	161	56.4	63	48	74	26	66
12,000....	0	35	72	50	46	24	62
12,000....	100	0	68	51	88	16	76
12,000....	100	35	69	58	85	25	74
12,000....	100	70	73	58	92	22	70
12,000....	200	35	66	48	92	24	76
15,674....	38	13.5	77	50	74	28	74
15,674....	38	56.4	78	60	80	20	81
15,674....	161	13.5	70	62	92	22	84
15,674....	161	56.4	73	67	104	21	90
18,000....	100	35	68	57	92	22	68
			Additional Treatments				
12,000....	0	0	61	56	38	24	60
12,000[2] ..	100	35	68	56	90	16	71

Treatment			Locations (farms) on Nicollet soil			
Stand	N lb./acre	P lb./acre[1]	Grewe	Hansen	S. Sta.	SW. Sta.
12,000....	100	35	100	94	100	85
15,101....	38	13.5	105	111	122	82
15,101....	38	56.4	107	110	118	98
15,101....	161	13.5	117	109	118	94
15,101....	161	56.4	104	118	122	113
20,000....	0	35	92	122	134	95
20,000....	100	0	128	130	140	86
20,000....	100	35	134	126	142	116
20,000....	100	70	148	132	145	114
20,000....	200	35	150	128	142	110
24,900....	38	13.5	131	131	140	100
24,900....	38	56.4	113	127	158	97
24,900....	161	13.5	138	132	159	110
24,900....	161	56.4	159	130	174	134
28,000....	100	35	157	134	158	134

[1]13.5, 35, 56.4,and 70 lb. per acre P are equivalent to 31, 80, 129, and 160 lbs. per acre P_2O_5, respectively.

[2]15 lb. Zn as Zn SO_4 broadcast on this plot.

TABLE 14.--Statistical response of corn yield to stand, nitrogen, and phosphorus--1960

Location (farm)	Linear b values from the multiple regression equation		F test phosphorus
	Stand	Nitrogen	
Aastad Soil			
Hubbard.....	0.432	[1]-3.582	5 percent
Johnson.....	2.020	8.832	[2]NS
Krueger.....	11.835	-3.668	5 percent
Rieppel.....	1.010	*[3]24.418	NS
W. C. Exp. Sta..	[2]-0.145	4.250	NS
Barnes Soil			
Cook.....**[3]14.868		-3.582	NS
Frensko..... **8.732		-1.708	NS
Grothe.....	9.598	**18.208	NS
Pufahl.....**-12.845		-1.582	5 percent
Siira.....	7.290	2.458	1 percent
Kranzburg Soil			
Berger.....	-6.278	-3.708	NS
Puhr.....**-11.402		-1.918	NS
Heikes.....	5.990	4.042	NS
Nelson.....**-11.692		-1.582	5 percent
Wilson.....	0.072	-0.125	NS
Nicollet Soil			
Bushard.....	-0.505	0.708	1 percent
Engstrom.....	2.525	**16.792	NS
Hansen..... **10.102		-1.500	NS
S.W. Exp. Sta. .	3.752	**13.832	NS
S. Exp. Sta. ...	5.558	3.292	5 percent

[1]A negative b value indicates yields decreased with increasing increments of the independent variable.

[2]NS means nonsignificant at the 5 percent level.

[3]*Shows statistical significance at the 5-percent level and ** at the 1-percent level.

was determined when organic matter was measured. Generally, the locations with least NO_3--N and organic matter showed response to N, but several plots with equally low amounts gave no response. Additional studies will be needed to evaluate factors involved in response to N.

Phosphorus--Response to this nutrient also varied with location and year. In 1960, 7 locations responded to P (5 positively and 2 negatively), whereas 4 locations showed positive response in 1961. Only 1 location--the Southwest Experiment Station--obtained response for the two consecutive years. Early growth response to P occurred at the Nelson and Pufahl locations, but final corn yields on these same plots were lower than on check plots.

In 1960, all the locations showing P response (except the Southwest Experiment Station) received above average June rainfall and all (except the Southern Experiment Station) received above normal August precipitation. Early growth response at Nelson and Pufahl was not sustained

TABLE 15.--Statistical response of corn yield to stand, nitrogen, and phosphorus--1961

Location (farm)	Linear b values from the multiple regression equation		
	Stand	Nitrogen	Phosphorus
Aastad Soil			
Hubbard	1.1573	1.4573	-1.5048
Johnson	[1]-0.1001	1.4521	1.8499
Krueger	-2.5135	**[2] 9.2717	**5.8706
Rieppel	-2.6976	-1.3159	-1.0943
W.C. Exp. Sta.	-1.0077	-1.7976	-2.1987
Barnes Soil			
Cook	6.5917	-1.1360	2.3160
Frederick	**8.6580	1.3367	1.4510
Frensko	**8.1629	*[2] 3.3134	*2.5083
Grothe	2.0958	*6.4582	1.4635
Pufahl	0.8862	-0.8250	2.3786
Kranzburg Soil			
Berger	**5.3697	-1.4374	1.7986
Foster	**4.8423	*1.9538	*1.5086
Heikes	**9.6367	**10.8464	1.9662
Nelson	-0.9888	-0.0612	0.0874
Wilson	**7.6283	*3.4159	-0.7249
Nicollet Soil			
Grewe	**15.1423	**11.8010	1.9720
Hansen	**10.2615	1.5086	0.4187
S.W. Exp. Sta.	**10.0138	**7.4859	**7.7280
S. Exp. Sta.	**18.2173	*3.6798	3.1624
Waubay-like Soil			
Juel	-4.3046	1.6624	1.7436

[1] A negative b value indicates yields decreased with increasing increments of the independent variable.

[2] *Shows statistical significance at the 5-percent level; ** at the 1-percent level.

probably because of low moisture reserves at planting time, whereas the remaining plots had adequate stored soil moisture. For the 2-year period, therefore, no consistent soil moisture-rainfall-P response relationships were observed except for the two previously mentioned negatively responding locations.

No definite relationship was observed between available soil P (Bray No. 1 extracting solution) and P response. All the low testing locations did not respond to P fertilization, and conversely, several high testing locations showed response to P. Evaluation of factors involved in P response will require further investigation for predicting response.

Potassium--The 1960 experiment included treatments to evaluate K response at all locations. None of the locations on Aastad, Barnes, and Kranzburg soils showed response to K, so no K

fertilizer was applied in 1961. Potassium varied from 0.29 to 2.04 meq. per 100 grams soil for the 0- to 6-inch depth. Response was obtained on Nicollet plots, however, so these plots received a blanket application of K fertilizer in 1961. Potassium on Nicollet plots varied from 0.27 to 0.88 meq. per 100 grams soil for the 0- to 6-inch depth.

Zinc--The 1961 experiment included one extra center point treatment per replicate for evaluating possible Zn deficiency at each location. Zinc (as $ZnSO_4$) was broadcast and disked in at the rate of 15 pounds per acre. No yield increases were obtained from the Zn-treated plots when compared to center point treatments without Zn at any location.

Fertilizer--Yield Relationships--Since one objective of this response surface study was to obtain a predictive equation for several input variables, the data must be combined over location-years. To evaluate the fertilizer (N and P)--yield relationship, the center point yield was compared with the calculated maximum yield in the sample space and the center point fertilizer rates with those applications corresponding to calculated maximum yields. Table 16 gives the results for 8 locations in 1961 and includes only those in which linear and quadratic mean squares or both were significant, and where lack of fit mean square was not significantly different from the mean square error. The small relative errors between actual and calculated center point yields compared to the larger errors for N and P rates indicate yields are not greatly affected even though N and P levels vary considerably from the center point rates. It appears, therefore, that N andP levels could be omitted as independent variables in multiple regression analysis over location-years without causing a serious error.

TABLE 16.--Relation of actual and calculated yields and fertilizer levels at center points for selected 1961 locations

Location (farm)	Center point yield of corn (Bu./acre[1]	Relative error in indicated variable when the calculated maximum within the experimental space is assumed to correspond to that observed at center point treatments[2]		
		Corn yield	N application	P application
Foster.....	58	2	15	47
Grothe.....	63	3	26	35
Johnson.....	80	6	-57	342
Krueger.....	80	14	83	98
Frensko.....	86	3	55	50
Frederick.....	91	4	54	43
SW Exp. Sta.	116	7	71	63
Gibbon.....	135	2	3	-227

[1] The N and P application on center point treatments was, respectively, 100 and 35 pounds per acre.

[2] $\text{Relative error} = 100 \left(\frac{\text{value observed at center point} - \text{value at calculated maximum}}{\text{value observed at center point}} \right)$

Response Surfaces

Each location produced a distinctive corn yield response surface for the input factors depending upon the uncontrolled variables for the particular year. Corn yields for each location were calculated from the regression coefficients for all combinations of stand, N, and P. The only way yields for all combinations of stand, N, and P can be presented is in table form (table 17).

TABLE 17.--Predicted yield of corn in bushels per acre for all combinations of the independent variables (Heikes--1961)

Levels of		P lb./acre				
Stand plants/acre	Nitrogen lbs./acre	0	17.5	35.0	52.5	70.0
	0	40	35	34	34	37
	50	58	53	52	52	55
6,000	100	68	64	62	62	65
	150	70	66	64	64	67
	200	64	60	58	58	61
	0	48	45	44	46	50
	50	67	64	64	65	70
9,000	100	79	76	75	77	81
	150	83	79	79	80	84
	200	78	75	74	76	80
	0	53	51	51	54	59
	50	74	72	72	75	80
12,000	100	86	84	85	88	93
	150	91	89	90	92	98
	200	88	86	87	89	94
	0	54	53	54	58	65
	50	76	75	77	81	87
15,000	100	90	89	91	95	101
	150	97	96	97	101	107
	200	95	94	95	99	106
	0	51	51	54	59	67
	50	75	75	78	83	90
18,000	100	90	90	93	98	106
	150	98	98	101	106	113
	200	98	98	100	106	113

Since graphic representation of response surfaces is limited to 3 dimensions, one variable must be held constant. Examples of yield response surface obtained are shown in figures 6 through 10 in which P was held constant at center point fertility. Figure 6 shows a surface where no response to stand or N was obtained so the surface appears flat. A response surface with stand response but no response to N is presented in figure 7. When both stand and N response occur, the surface is similar to figure 8. When a location has insufficient moisture, the response surface appears as in figure 9. Frequently the surface at one location will change from year to year since different growing conditions occurred (fig. 10). The problem is, therefore, one of combining locations over years so as to account for the factors causing the differences. Results of combining locations over years are presented in the following sections.

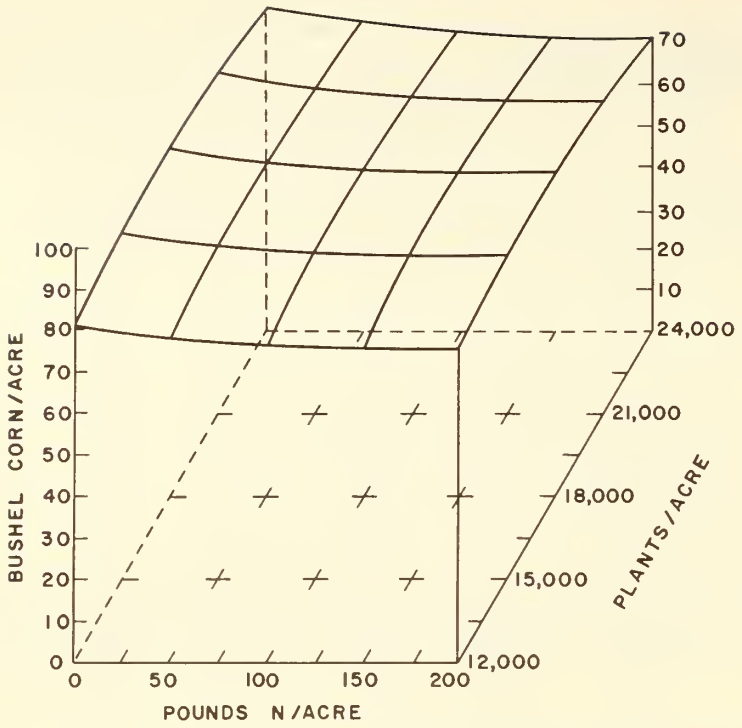


Figure 6.--Response surface with no yield response to stand or N. (West Central Experiment Station--1961--Aastad Soil)

$$\hat{Y} = 79.44 - 1.01S - 1.80N - 2.20P - 1.84S^2 + 0.79N^2 + 0.32P^2 - 0.19SN - 3.44SP + 0.56NP$$

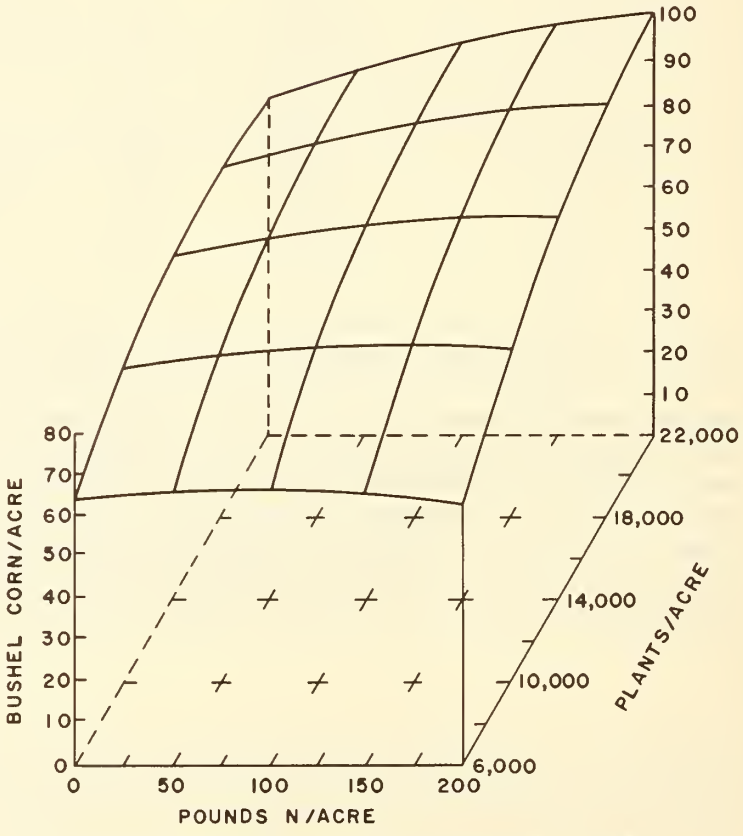
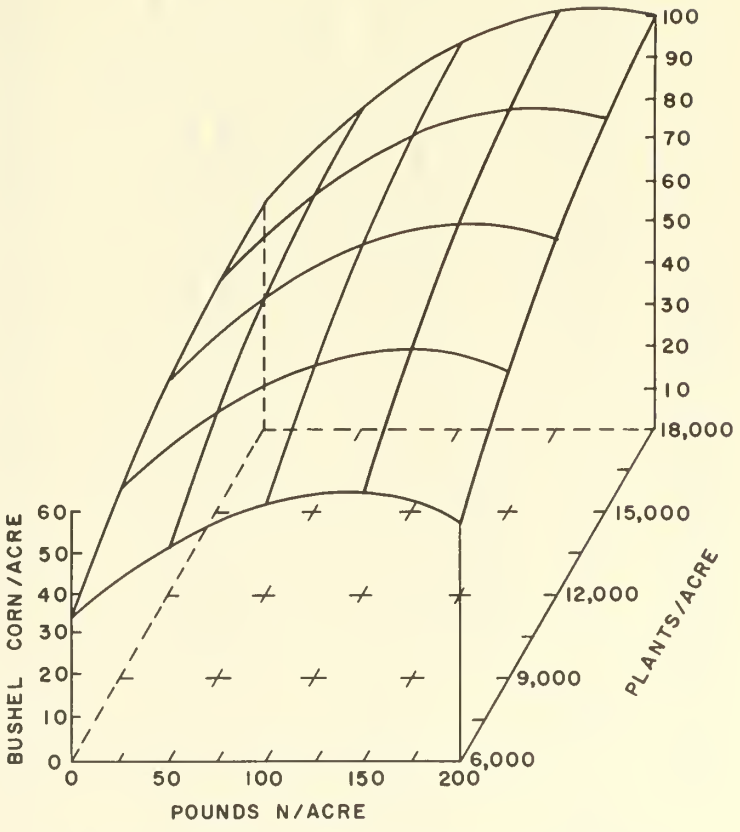


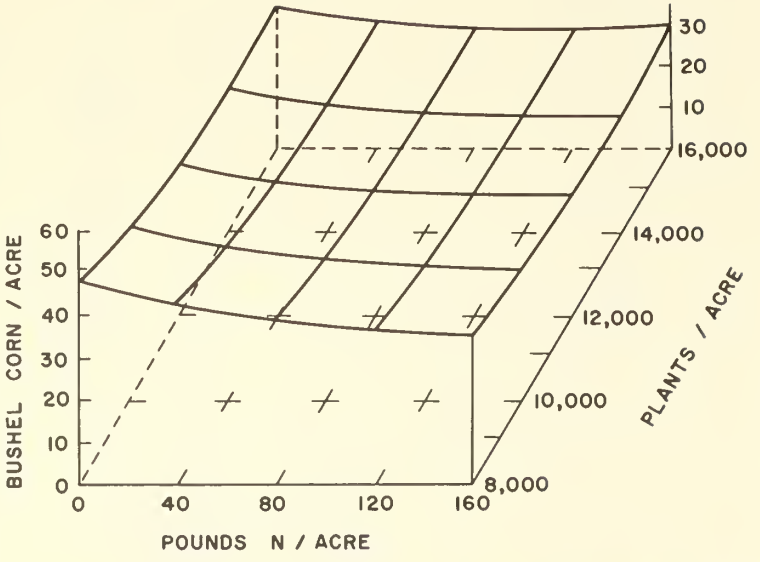
Figure 7.--Response surface with yield response to stand. (Frederick--1961--Barnes Soil)

$$\hat{Y} = 90.61 + 8.66S + 3.01N + 3.27P - 3.78S^2 - 1.15N^2 - 1.53P^2 + 2.12SN + 2.88SP + 0.75NP$$



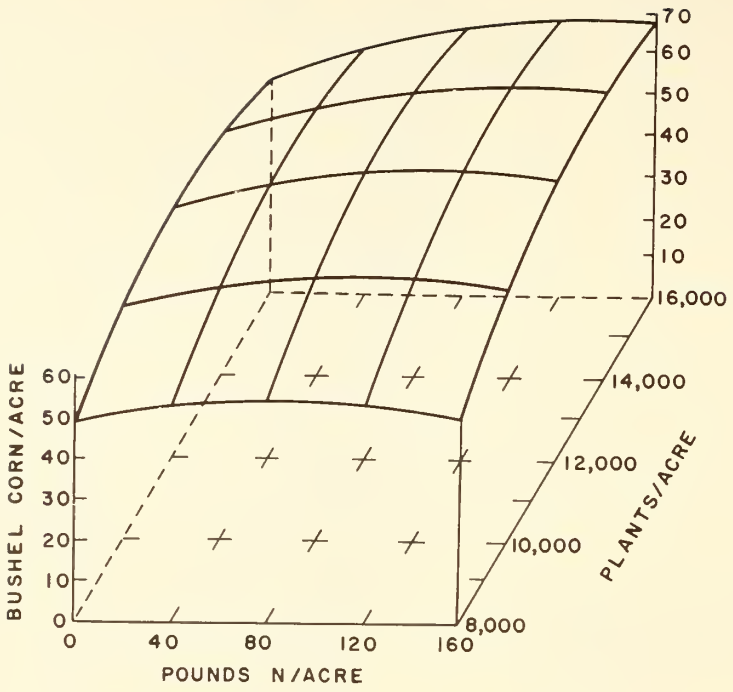
$$\hat{Y} = 84.76 + 9.64S + 10.85N + 1.97P - 2.76S^2 - 5.95N^2 + 1.83P^2 + 2.06SN + 1.69SP - 0.62NP$$

Figure 8.--Response surface with yield response to stand and N. (Heikes--1961--Kranzburg Soil)



$$\hat{Y} = 29.832 - 3.708N - 6.278S + 2.792N^2 + 5.375S^2 + 2.452NS$$

Figure 9.--Response surface for location with insufficient moisture. (Berger--1960--Kranzburg Soil)



$$\hat{Y} = 69.582 + 4.042N + 5.99S - 5.332N^2 - 13.582S^2 + 3.898NS$$

Figure 10.--Response surface which changed between years.[1]
(Heikes--1960--Kranzburg Soil)

[1] See figure 8 for Heikes response surface in 1961.

III. PREDICTION OF YIELD

In this area corn yields are highly dependent on efficient use of moisture, so crop response to management varies with changes in precipitation and temperature. Each year the farmer must decide what population to plant and the kind and amount of fertilizer to apply. If a simple, but reliable, prediction equation could be used, near optimum returns could be obtained.

The development of a yield prediction equation is still in progress. To date two multiple regressions have been computed for center point treatments over location-years (locations (farms) on Aastad, Barnes, and Kranzburg soils). Since center point treatments only were initially used, stand and fertility were excluded as variables. Justification for omitting fertility as an independent variable over location-years was discussed previously.

Multiple regression equations were computed for 1960 data, 1961 data, and the 2 years combined. Corn yields for each center-point treatment were used in calculating the regression equations and fertility variables eliminated since yields varied only slightly about the center points. Values of R and R^2 for each equation and their significance are given in table 18. The first regression equation for 1960-61 (10 independent variables), containing linear and quadratic terms for available soil moisture at planting time and linear terms for rainfall, is as follows:

$$\hat{Y} = -44.01 + 12.91SM - 6.665P_1 + 0.155P_2 + 10.70P_3 + 1.818P_4 + 13.37P_5 + 12.27P_6 + 0.852P_7 + 0.939P_8 - 0.456SM^2 \quad (4)$$

where $\hat{Y}$ is estimated yield in bushels per acre, SM is available soil moisture at planting time to a depth of 5 feet, and P_1 through P_8 are precipitation for the following periods: P_1--May 15-31;

P_2--June 1-14; P_3--June 15-30; P_4--July 1-14; P_5--July 15-31; P_6--August 1-14; P_7--August 15-31; and P_8--September 1-14.

The second multiple regression for 1960-61 (18 independent variables) was similar to the first except that interaction terms for soil moisture at planting time with rainfall (for P_1 through P_8) were added. Inclusion of these interactions increased the R^2 value (60-61 equation) to 0.75. With the addition of more independent variables, the R^2 value should increase, but the equation may become too complicated for practical use (as a predictive tool) and be difficult to interpret based on physical factors.

Use of the first regression equation for yield prediction is illustrated as follows: When long term average precipitation for periods 1 through 8 was substituted into the 60-61 equation, the predicted corn yields were 62, 77, and 88 bushels per acre, respectively, for 5, 7, and 9 inches of available soil moisture at planting time. Thus a farmer planting center point stands (depending on soil) and fertilizing with 100 pounds N and 35 pounds P (80 lbs. P_2O_5) per acre (broadcast) can determine soil moisture reserves at planting and obtain a reasonable yield estimate (assuming average rainfall for each period).

Obviously more detailed studies are needed to refine the equations developed to date. Stand, fertility, and soil temperature are variables which need to be included, and any prediction equation must be based on rainfall probability. The equation developed from 2 years' data did account for most of the yield variation, but this is probably because moisture is the most critical factor for corn production in this area. Studies are presently underway to provide the needed information for refining the present prediction equation.

TABLE 18.--Values of R and R^2 and associated degrees of freedom for multiple regression equations

Year	Regression equation with 10 independent variables			Regression equation with 18 independent variables		
	R	R^2	df	R	R^2	df
1960.....	**[1]0.887	0.787	168	**0.935	0.875	160
1961.....	**0.874	0.763	169	**0.911	0.830	161
60-61.....	**0.834	0.695	348	**0.864	0.747	340

[1] **Shows statistical significance at the 1-percent level.

SUMMARY

The response surface approach used to evaluate production factors of corn provided sufficient information to characterize the area as to soil and environmental factors during the 2 years studied. The results so far have not yielded good prediction equations, but work is continuing to improve the initial regressions.

Available soil moisture at planting time for the 2-year period varied from 3.18 to 10.47 inches, and growing season precipitation was 5.58 to 20.78 inches. In 1960, when below average rainfall was received during the critical growth period, corn yields were related to stored soil moisture, whereas in 1961, corn yields were not significantly related to stored soil moisture because most locations received above average July rainfall thus minimizing the effect of stored soil water.

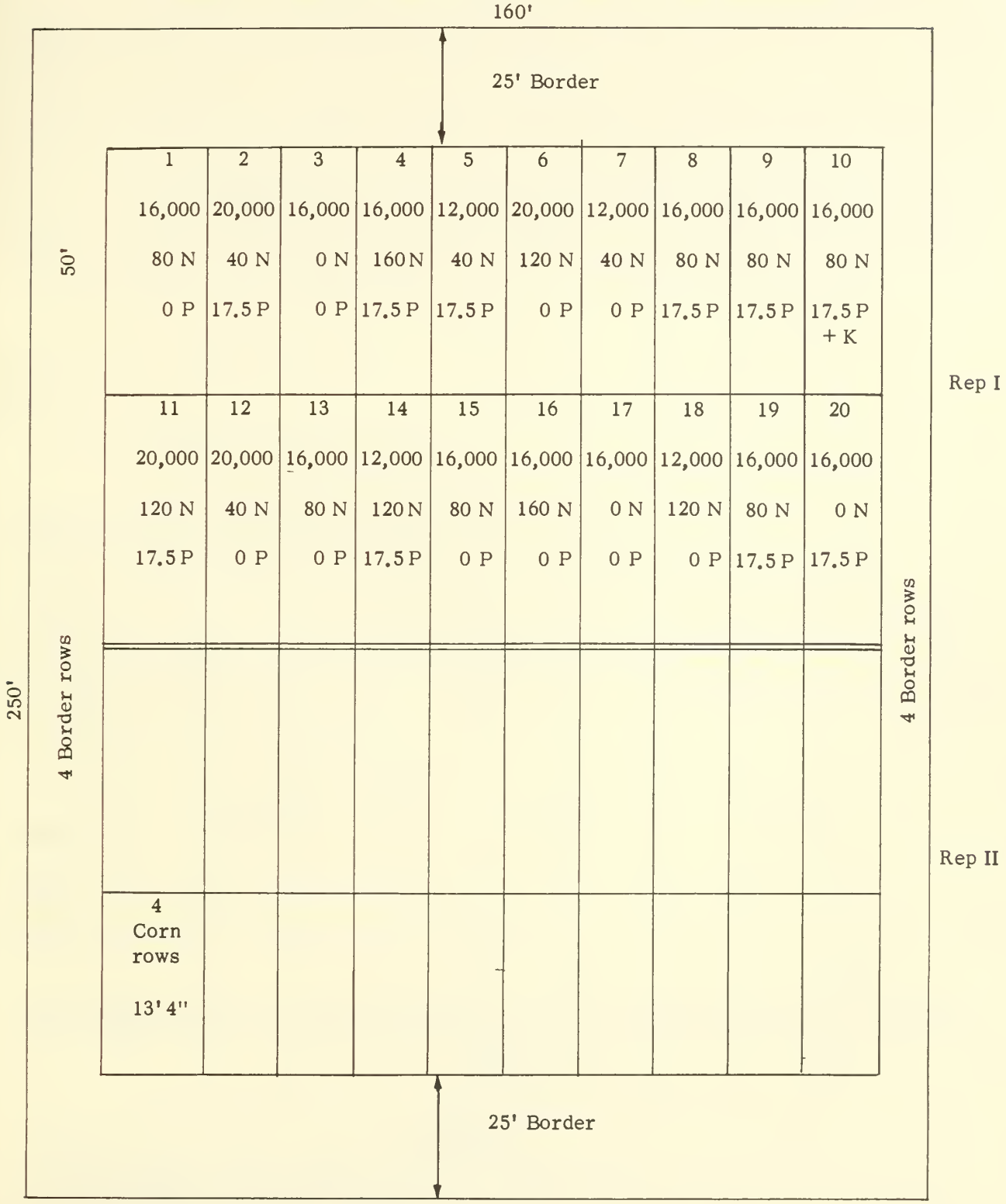
Corn grain yield response to stand and N occurred at 13 of 40 locations for each variable during the 2-year period, whereas 11 locations showed response to P (two negative) during this period. Locations responding to nitrogen may or may not have responded to stand, and the same locations did not always respond the same in both years. Response to stand and N appeared

related to above average rainfall during the critical growth period, because most response to both variables occurred in 1961 when July rainfall was above average. No consistent moisture relationship was observed for P response.

Multiple regressions for predictive purposes were initially calculated for center point treatments, so no stand and fertility variables were included. The regression equation, including only soil moisture and rainfall variables, gave an R^2 value of 0.70 for yield data combined over the 2-year period and indicates that moisture is one of the most critical production factors for corn in this area. More detailed studies are needed and are in progress for including stand and fertility variables in the prediction equation.

APPENDIX I--FIELD PLOT DIAGRAMS

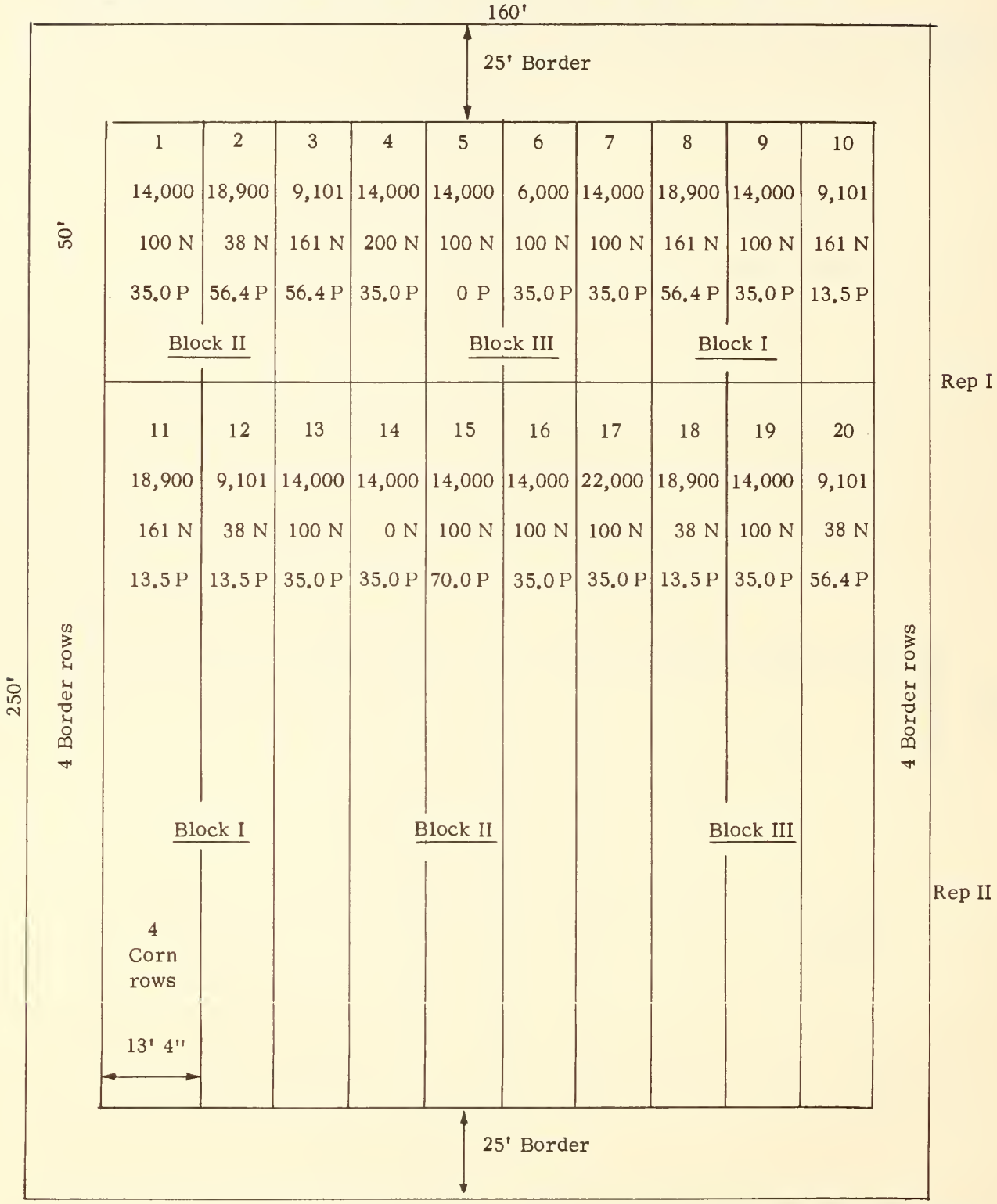
Figure 11.--Sample field plot layout for the 1960 composite design[1].



1	2	3	4	5	6	7	8	9	10
16,000	20,000	16,000	16,000	12,000	20,000	12,000	16,000	16,000	16,000
80 N	40 N	0 N	160 N	40 N	120 N	40 N	80 N	80 N	80 N
0 P	17.5 P	0 P	17.5 P	17.5 P	0 P	0 P	17.5 P	17.5 P	17.5 P + K
11	12	13	14	15	16	17	18	19	20
20,000	20,000	16,000	12,000	16,000	16,000	16,000	12,000	16,000	16,000
120 N	40 N	80 N	120 N	80 N	160 N	0 N	120 N	80 N	0 N
17.5 P	0 P	0 P	17.5 P	0 P	0 P	0 P	0 P	17.5 P	17.5 P

[1] Treatments were randomized within each rep.; stand is given in plants per acre; N and P are given in lb. per acre; and +K is 50 lb. per acre K.

Figure 12.--Sample field plot layout for the 1961 central composite design[1].



[1] Treatments were randomized within each block and blocks within each rep. Stand is given in plants per acre; N and P in lb. per acre.

APPENDIX II--CALCULATIONS FOR TREATMENT LEVELS

CALCULATION OF STAND AND NITROGEN LEVELS--1960

A sample calculation for determining levels of stand and N for Barnes soil will illustrate the procedure. L_1 and L_3 were assigned 8,000 and 16,000 plants per acre, respectively, the minimum and maximum stands to be tested. These correspond to coded values of -0.866 and 0.866, respectively. L_2 (with coded value of 0) is midway between L_1 and L_3; therefore, it must take the level of 12,000 plants per acre. For N levels, L_1 and L_5 were assigned 0 and 160 pounds per acre, respectively, the minimum and maximum rates to be tested. These correspond to coded values -1.000 and +1.000, respectively. Since L_3 (with coded value of 0) is midway between L_1 and L_5, it must be 80 pounds per acre. L_2 is in proportion to the coded values, i.e., it is 0.5/1.00 of the difference in N rate from 80 to 0.

$$L_2 = 80 - (80 \times \frac{0.5}{1.0}) = 40 \text{ lb. N per acre}$$

Similarly,

$$L_4 = 80 + (80 \times \frac{0.5}{1.0}) = 120 \text{ lb. N per acre}$$

CALCULATION OF STAND, NITROGEN, AND PHOSPHORUS LEVELS--1961

A sample calculation for determining levels of stand for Barnes soil will illustrate these calculations. L_1 and L_5 were assigned 6,000 and 22,000 plants per acre, respectively, the minimum and maximum stands to be tested. These correspond to coded values -1.633 and 1.633, respectively. L_3 (with coded value of 0) falls midway between L_1 and L_5; hence, it must take the value of 14,000. L_2 is in proportion to the coded values, i.e., it is 1/1.633 of the difference in stand from 14,000 to 6,000 (8,000 difference).

$$L_2 = 14{,}000 - (8{,}000 \times \frac{1}{1.633}) = 9{,}101$$

Analogously,

$$L_4 = 14{,}000 + (8{,}000 \times \frac{1}{1.633}) = 18{,}899$$

Similar calculations are made for the N and P levels.

APPENDIX III--LOCATIONS OF COOPERATORS' FARMS 1960

Aastad Soil

1. Harold Hubbard, Grant County, Barrett, Minn.
2. Curtis Johnson, Yellow Medicine County, Clarkfield, Minn.
3. Royal Krueger, Lyon County, Tracy, Minn.
4. Erich Rieppel, Swift County, Appleton, Minn.
5. West Central Experiment Station, Stevens County, Morris, Minn.

Barnes Soil

1. Ray Cook, Stevens County, Alberta, Minn.
2. Cecil Frensko, Lincoln County, Ivanhoe, Minn.
3. Walter Grothe, Swift County, Benson, Minn.
4. Jim Pufahl, Grant County, Milbank, S. Dak.
5. Siira Brothers, Douglas County, Brandon, Minn.

Kranzburg Soil

1. Norman Berger, Lincoln County, Lake Benton, Minn.
2. George Heikes, Nobles County, Ellsworth, Minn.
3. Carl Nelson, Codington County, Watertown, S. Dak.
4. L. F. Puhr, Brookings County, Brookings, S. Dak.
5. Kenneth Wilson, Pipestone County, Pipestone, Minn.

Nicollet Soil

1. Walter Bushard, Sibley County, Gibbon, Minn.
2. Albert Engstrom, Martin County, Dunnell, Minn.
3. Erwin Hansen, Watonwan County, Butterfield, Minn.
4. Southern Experiment Station, Waseca County, Waseca, Minn.
5. Southwest Experiment Station, Redwood County, Lamberton, Minn.

1961

Aastad Soil

1. Harold Hubbard, Grant County, Barrett, Minn.
2. Curtis Johnson, Yellow Medicine County, Clarkfield, Minn.
3. Royal Krueger, Lyon County, Tracy, Minn.
4. Erich Rieppel, Swift County, Appleton, Minn.
5. West Central Experiment Station, Stevens County, Morris, Minn.

Barnes Soil

1. Ray Cook, Stevens County, Alberta, Minn.
2. Orville Frederick, Grant County, Barrett, Minn.
3. Cecil Frensko, Lincoln County, Ivanhoe, Minn.
4. Walter Grothe, Swift County, Benson, Minn.
5. Jim Pufahl, Grant County, Milbank, S. Dak.

Kranzburg Soil

1. Norman Berger, Lincoln County, Lake Benton, Minn.
2. Rodney Foster, Brookings County, Brookings, S. Dak.
3. George Heikes, Nobles County, Ellsworth, Minn.
4. Carl Nelson, Codington County, Watertown, S. Dak.
5. Kenneth Wilson, Pipestone County, Pipestone, Minn.

Nicollet Soil

1. Waldemar Grewe,[1] Sibley County, Gibbon, Minn.
2. Erwin Hansen, Watonwan County, Butterfield, Minn.
3. Maurice Simons, Redwood County, Morton, Minn.
4. Southern Experiment Station, Waseca County, Waseca, Minn.
5. Southwest Experiment Station, Redwood County, Lamberton, Minn.

Waubay-like Soil

1. John Juel, Lincoln County, Harrisburg, S. Dak.

[1] This location is not used due to crop injury.

APPENDIX IV--MEASUREMENTS

The soil and plant characteristics measured during this experiment are listed below.

1. Soil moisture profile at planting time.
   a. Ten sampling sites (5 per replicate) were measured at each location. These sites were randomized over each replicate.
   b. Soil samples were collected in 6-inch increments to a depth of 2 feet and in 12-inch increments at depths of 2 to 5 feet.
   c. Samples were collected, placed in tared moisture cans, and sealed with masking tape until weighed. Samples were then oven-dried at 105° C. for 48 hours and reweighed.
2. Soil moisture profile at 1 foot plant height (35 days after planting) was measured in 1961 on center point treatments. The same procedure described in 1 was used.
3. Soil moisture profile at tasseling (65 days after planting) was measured in 1961 on center point treatments using the same procedure described in 1.
4. Bulk density was determined for each sample depth to convert soil moisture measurements to a volume basis. Ten cores per sample depth were taken with a Viehmeyer tube and averaged.
5. Rainfall was recorded daily by the farmer cooperator on addressed record cards and sent to the Morris Station. Wedge type rain gauges were used.
6. Complete soil profile samples for chemical analyses were taken at the time of moisture sampling. A small portion of each core was saved and composited by sample depths in each replicate. Analyses included:
   a. Organic carbon
   b. Available P
   c. Exchangeable K
   d. Nitrifiable N
7. One-third and 15-atmosphere tensions were measured on composite samples of each sample depth. These values were used for calculating available soil moisture and to estimate maximum water holding capacity.
8. Early growth measurements.
   a. Corn height measurements were made at time of estimated maximum differential of plant heights as determined by visual observations. Twenty plants per plot were selected at random for measurement.
   b. Whole plant samples were taken in 1960. Ten plants (5 from each exterior row) were taken for dry weight determinations at the same time height was measured.

9. Corn leaf samples at silking.
   a. Twenty leaves per plot were randomly sampled from the interior rows for N and P analyses. The first leaf below and opposite the ear leaf was selected from 20 plants.
   b. Leaf samples were taken for spectrographic analyses from check plots and center point treatments and sent to Beltsville for analysis. Elements determined were K, Ca, Mg, P, B, Fe, Mn, Cu, Zn, Na, and Al.
10. Corn silking dates by treatment were determined as often as time allowed.
11. September whole plant samples were taken at random in 1961 from exterior rows (10 plants per plot). Total N, P, and K were determined for measuring nutrient uptake of each element.
12. Corn was harvested from 30-foot lengths of the two interior rows. A total number of ears harvested and number of plants were recorded. A 20-pound subsample was taken for shelling percentage determination.
13. Estimates of weeds, insects, and lodging were made for each treatment at approximately 3-week intervals throughout the growing season.
14. Daily average temperatures were obtained from the nearest weather station.
15. Bulk soil samples for greenhouse studies were taken at each location before fertilizer was applied.

Several prepared forms were used to assure uniform recording of data for every measurement at each location.

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